February 1979

THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

Measuring a Complex Casting

U.S. Department of Commerce
Maritime Administration
in cooperation with
Todd Pacific Shipyards Corporation

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **FEB 1979**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE
The National Shipbuilding Research Program Measuring a Complex Casting

5a. CONTRACT NUMBER
5b. GRANT NUMBER
5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER
5e. TASK NUMBER
5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Surface Warfare Center CD Code 2230 - Design Integration Tools Building 192 Room 128-9500 MacArthur Blvd Betheda, MD 20817-5700

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR’S ACRONYM(S)

11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**15**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

FOREWORD

This report is organized for insert in "'Photogrammetry in Shipbuilding" July 1976; publication number PB-262-130/AS, National Technical Information Service, Springfield, VA 22161. It results from one of the many projects managed and cost shared by Todd Pacific Shipyards Corporation as part of the National Shipbuilding Research Program. The Program is a cooperative effort by the Maritime Administration's Office of Advanced Ship Development and the U.S. shipbuilding industry. The objective, described by the Ship Production Committee of the Society of Naval Architects and Marine Engineers, emphasizes productivity.

The research was assigned to:

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Appreciation is expressed for the assistance received from R. C. Confer, J. F. Curtis, P. M. Dowries. K. A. Lyons and D. M. Prowse of Todd Pacific Shipyards Corporation, Seattle Division.

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EXECUTIVE SUMMARY

Within the last three years photogrammetry has been employed in real production situations by six shipbuilders in the United States. Five of them have applied the process repeatedly for:

- surveys to predict the fit of 126,000 DWT tankships built in halves,
- measuring city-block size subassemblies for the world's largest offshore platform,
- determining the circularity of Trident class submarine hulls,
- verifying that Conch type and spherical LNG tanks are within dimensional tolerances and producing LNG tank sounding tables of unprecedented accuracy.

Some ship and airplane builders in the United States are already considering in-house capabilities. They appreciate photogrammetric measurement because it imposes the least interference with ongoing production and the photographs used are ix-refinable permanent records.

This report describes a procedure for obtaining accurate dimensions of a complex casting. It should be of particular interest to quality assurance people and those responsible for fitting a casting to adjoining structure.

Page 11 is especially noteworthy because it describes potential productivity gains in the entire process associated with complex castings including design, inspection and installation. It also identifies benefits that could be obtained, without the application of photogrammetry, if shipbuilders impose certain nominal dimensioning requirements on designers and if certain marking instructions are included in purchase specifications for castings.

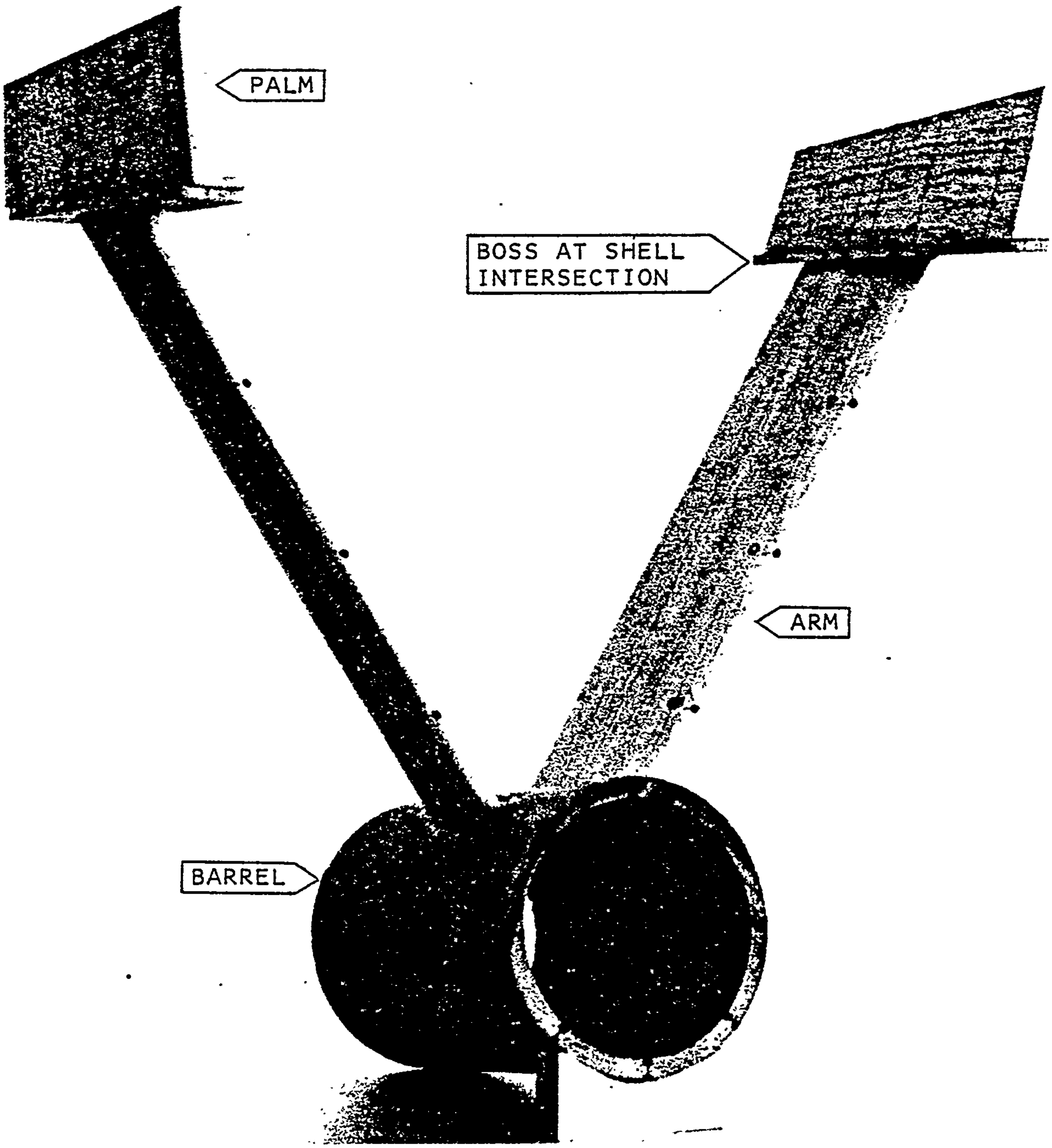

FIGURE 2-23: Model of Strut. This 16½-inch high model was used by the photogrammetrist to plan a photographic scheme. The scale is 1" = 1'.

2.6 Survey of a Strut Casting

A 24-ton strut casting[1] was made available by Todd Pacific Shipyards Corporation for the purpose of demonstrating a photogrammetric procedure for producing a precise survey of its complicated three 'dimensional form. Although more common single-screw sternframe castings are different from strut castings the photogrammetric techniques described herein still apply. Also, casting size is virtually immaterial to the photogrammetric process. However, size would impact on the services needed for handling a casting and positioning camera stations.

2.6.1 Preparation

To permit the photogrammetrist to conveniently study the geometry of the casting the shipyard provided the simple model pictured in Figure 2-23, the designer's drawings, and a sketch from the shipyards' quality assurance (QA) inspector showing the measurements desired. These three sources of information were the bases for a plan to photograph the strut. This plan also allowed the shipyard to conveniently prepare for:

- services to support the casting in an upright position to facilitate relatively unobstructed photographic views,
- loan of an angle iron on which to mark accurate scale references,
- placement of targets,
- a forklift-raised platform for elevated camera stations, and
- use of a darkroom, or a space that could be adapted, for developing exposed plates.

2.6.2 Photogrammetric Procedures

The photogrammetrist arrived at the shipyard late on an afternoon. Approximately two hours were spent inspecting the casting (not yet set upright), preparing the darkroom, and in general discussions with shipyard personnel. The QA inspector started placing targets on the casting at points of principal need, i.e., for confirming the strut palm positions relative to the barrel and to verify the arm twist angles. In order to facilitate comparison of photogrammetrically obtained measurements with the design, the QA inspector selected points corresponding to the intersection of strut palm edges with frame lines and strut arm leading and trailing edges with station lines as shown on the designer's drawings.

On the following morning the casting was set upright in a area where photographs could be taken from several different angles. Placement of targets[2], provided by the photogrammetrist, was completed according to the plan illustrated in Figures 2-24.

In instances where a target extended beyond an edge of the casting, a putty-like substance was placed behind the unattached portion of the target for added support; see Figure 2-25.

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[1] Actually a composite of times seperate castings welded together.

[2] A target consisted of a 0.15-inch flat-white bull's-eye upon a (nominal) 1½-inch square flat-black background. They were offset printed on mailing label stock which features a "crack-n-peel" backing and a permanent adhesive. The manufacturer of the stock is Fasson of Painesville, Ohio.

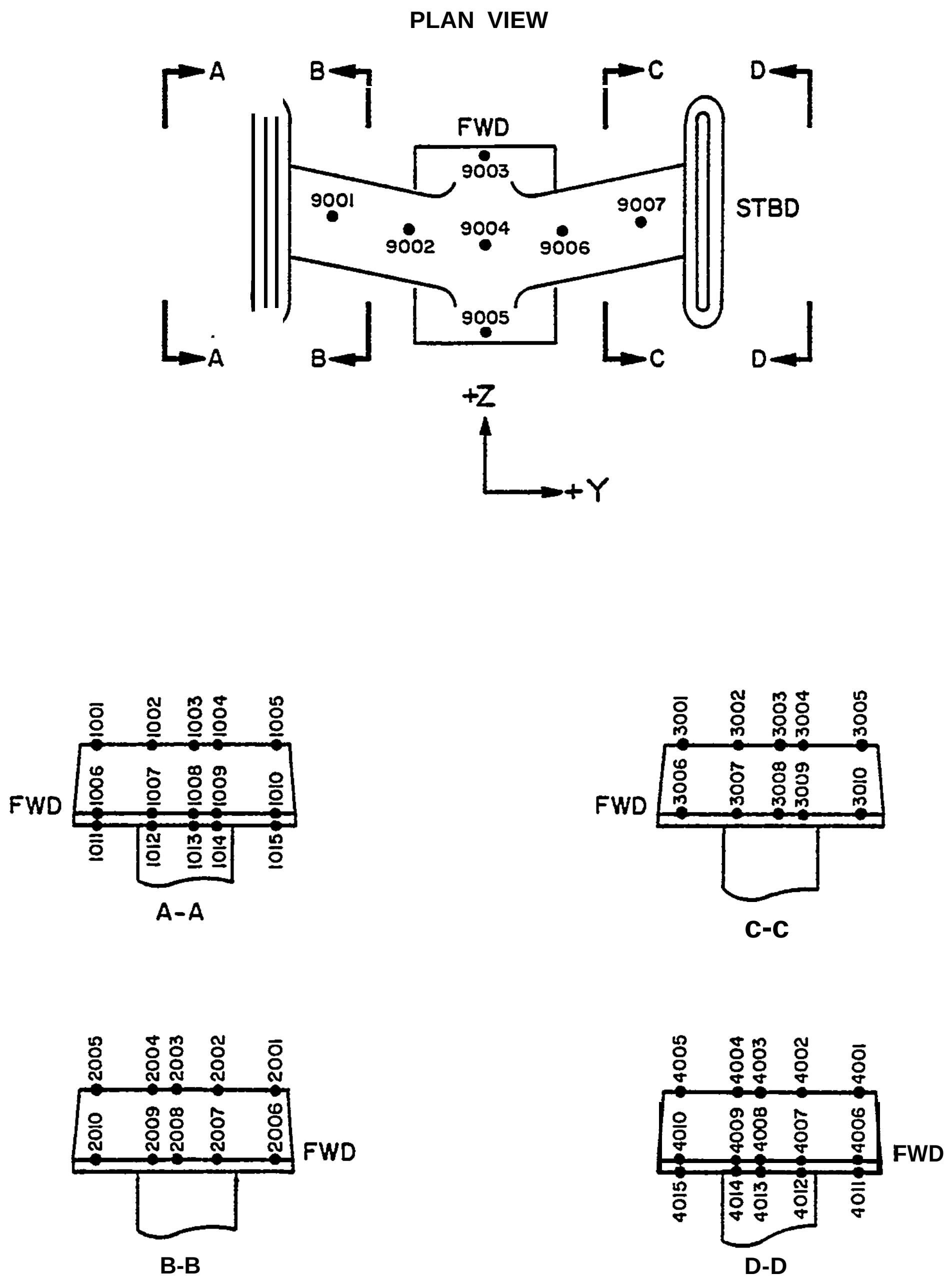

FIGURE 2-24a: Target Locations. Most were designated by the shipyard's QA inspector. 9000 series numbers designate "tie in" targets needed in the photogrammetric solution for accurately determining the locations of camera stations relative to each other.

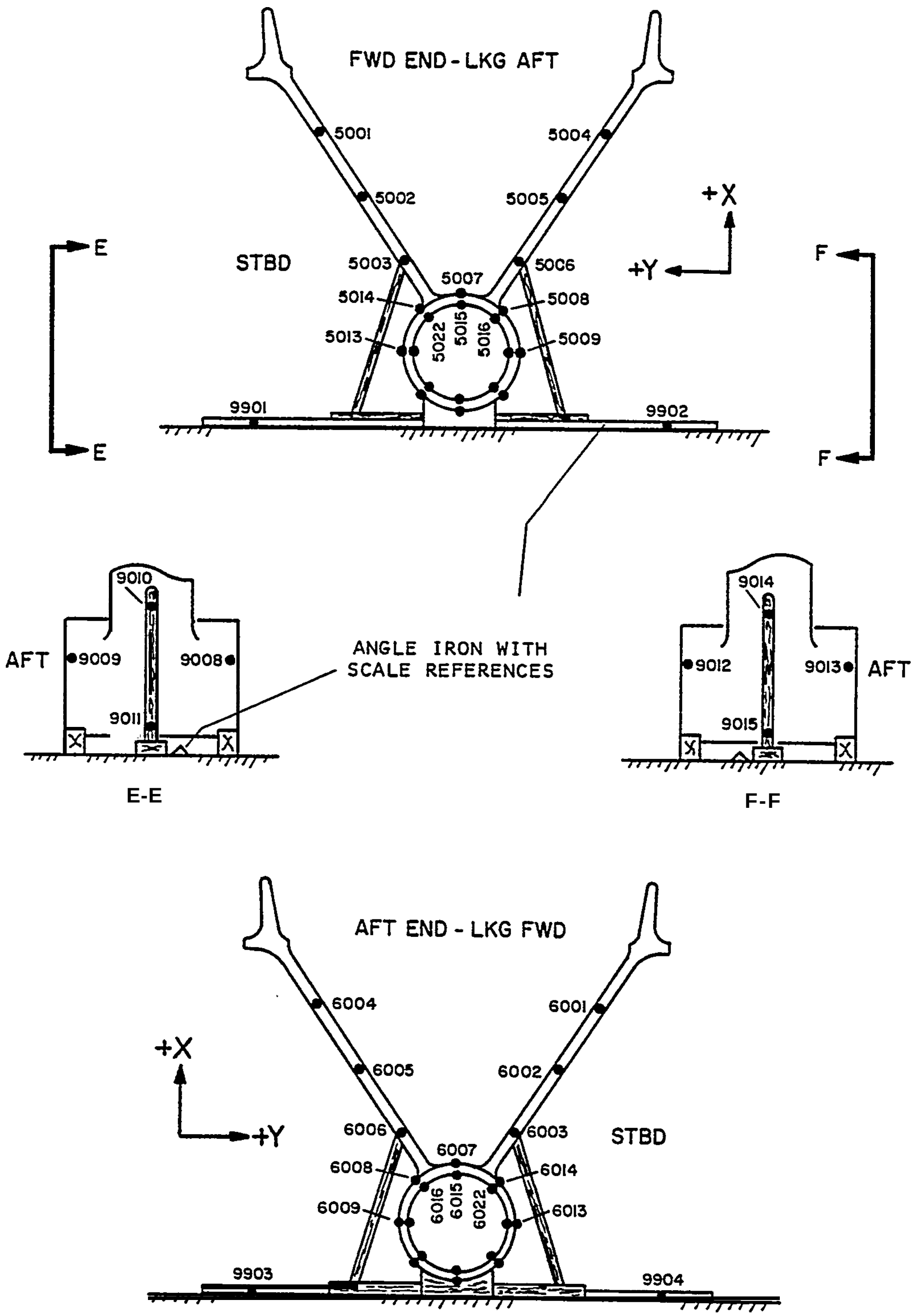

FIGURE 2-24b: Target Locations. The distances, measured with a special tape, between 9901 and 9902 and between 9903 and 9904 are the scale references. Other 9000 series numbers designate "tie in targets".

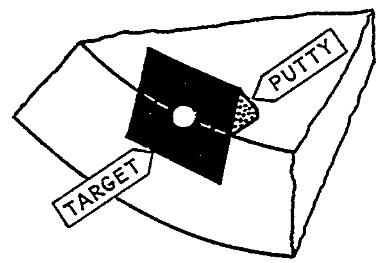

FIGURE 2-25: Material to Maintain Flatness. The target shown is on the inside circumference of the barrel. A "putty" successfully used for this purpose was Johns-Manville "Duxseal" often used by shipbuilders to seal against water, air and dust in plumbing, electrical and HVAC systems.

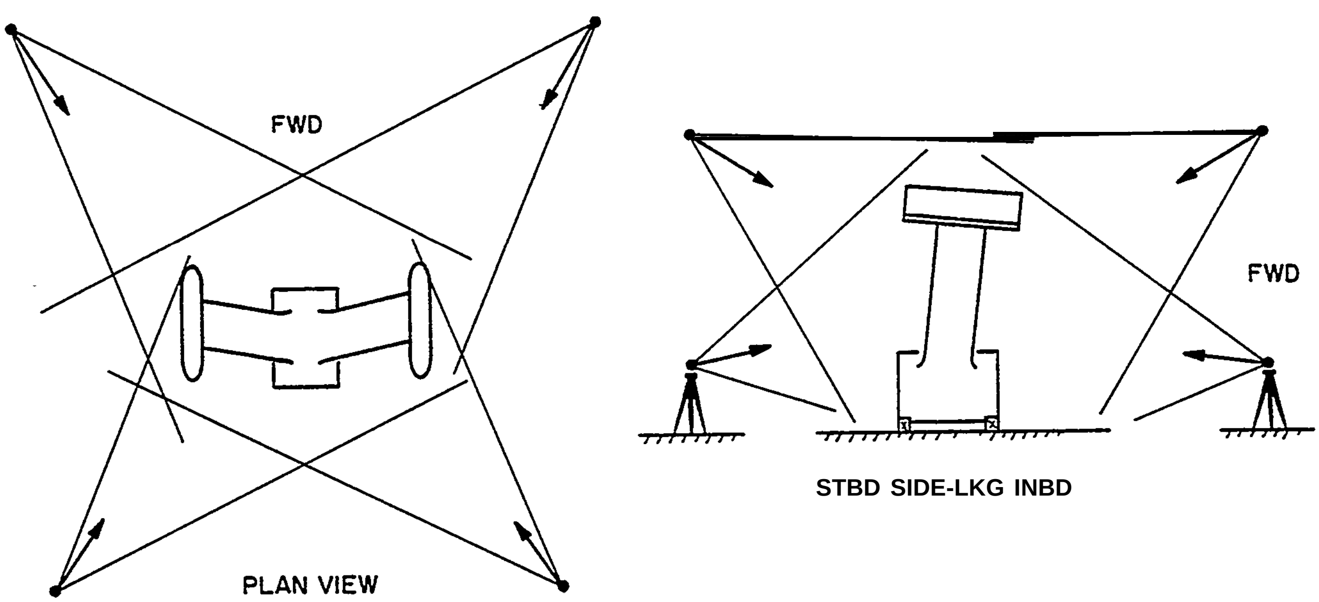

FIGURE 2-26: Camera Locations. Lack of complete symmetry is due to forward "lean" of the strut arms. It was necessary to know only the approximate locations of the camera stations. Precise determinations were a by-product of the data processing.

To provide a reference for establishing a correct scale in the photogrammetric solution, two targets were attached about 18 feet apart on each leg of a 2" x 2" angle iron. The exact distance between each pair[1] on a leg was measured with a steel survey tape stretched under ten-pounds tension. To facilitate accuracy each leg surface of the angle iron was kept horizontal during measurement so that the tape would be supported throughout its length. For each pair of targets five measurements were recorded to the nearest 0.001 foot. Averages, corrected for temperature, were used as the scale references. Afterward, the angle iron was placed, bosom down, beneath the strut barrel and weighted so that it would remain stationary. Figure 2-24b illustrates the location of the angle iron.

Photographs of the casting were taken over a period of 2½ hours from the locations shown in Figure 2-26. This period included a lunch break, during which several exposed plates were developed. Two were found unsatisfactory because of a very low sun angle and were retaken later in the reported time period when the sun was higher in the sky. By 14:00 hours all plates had been developed and inspected. At this time the shipyard was notified that access to the casting was no longer required.

All exposures were taken with the Wild P31 camera illustrated in Appendix B, Figure B-2.* Glass plates coated with a panchromatic emulsion served as the recording medium to assure maximum geometric stability of the recorded imagery. Photographs from the ground and from overhead were taken with the camera mounted on a tripod. A forklift was used to elevate the camera, tripod and operator for the exposures from overhead; see Figure 2-27. Figure 2-28 is a print made from one of the original glass plate negatives.

2.6.3 Laboratory Measurements

At the photogrammetrist's facility each of the eight plates was examined with an ordinary magnifying glass. As each image of a target was located it was circled with ink on the emulsion-free side of the plate and also numbered according to a previously devised scheme which gave each target a unique number; see Figure 2-24. Each plate was then measured[2] on a Kern MK2 comparator like the one shown in Appendix B, Figure B-6*.

2.6.4 Data Processing

All measurements made on the plates were processed through a series of computer programs which triangulate the three dimensional locations of the targets by obtaining the overall "least squares" best-fit of all optical rays intersecting all of the targets[3]. This calculation was performed in an arbitrary three dimensional coordinate

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[1]Between targets numbered 9901 and 9902 and between 9903 and 9904 in Figure 2-24b.

*These references are in "Photogrammetry in Shipbuilding" July 1976 available from the National Technical Information Service, Springfield, VA 22161; publication number PB-262-130/AS.

[2]Measurement of the plates was subcontracted to Analytic Photo Control, Inc. of Indian Harbour Beach, Florida.

[3]This process is best described in "Predicting the Fit of Ships Built in Halves" by J.F. Kenefick and D. Douglas Peel, presented to the International Society of Photogrammetry Symposium 'Photogrammetry for Industry", Stockholm, Sweden, August 1978.

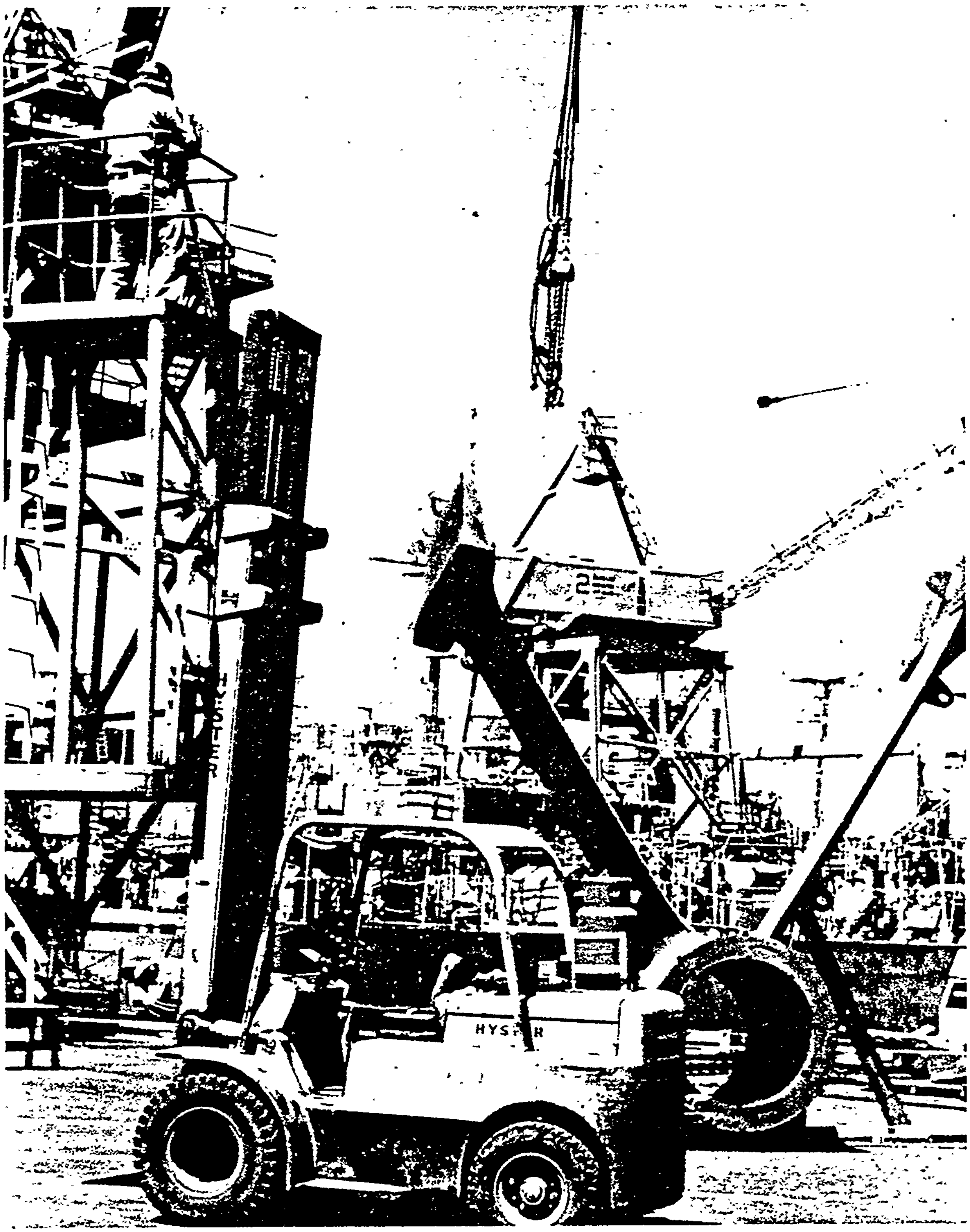

FIGURE 2-27: Platform and Forklift. Camera and operator (upper left) are about 21 feet above the ground.

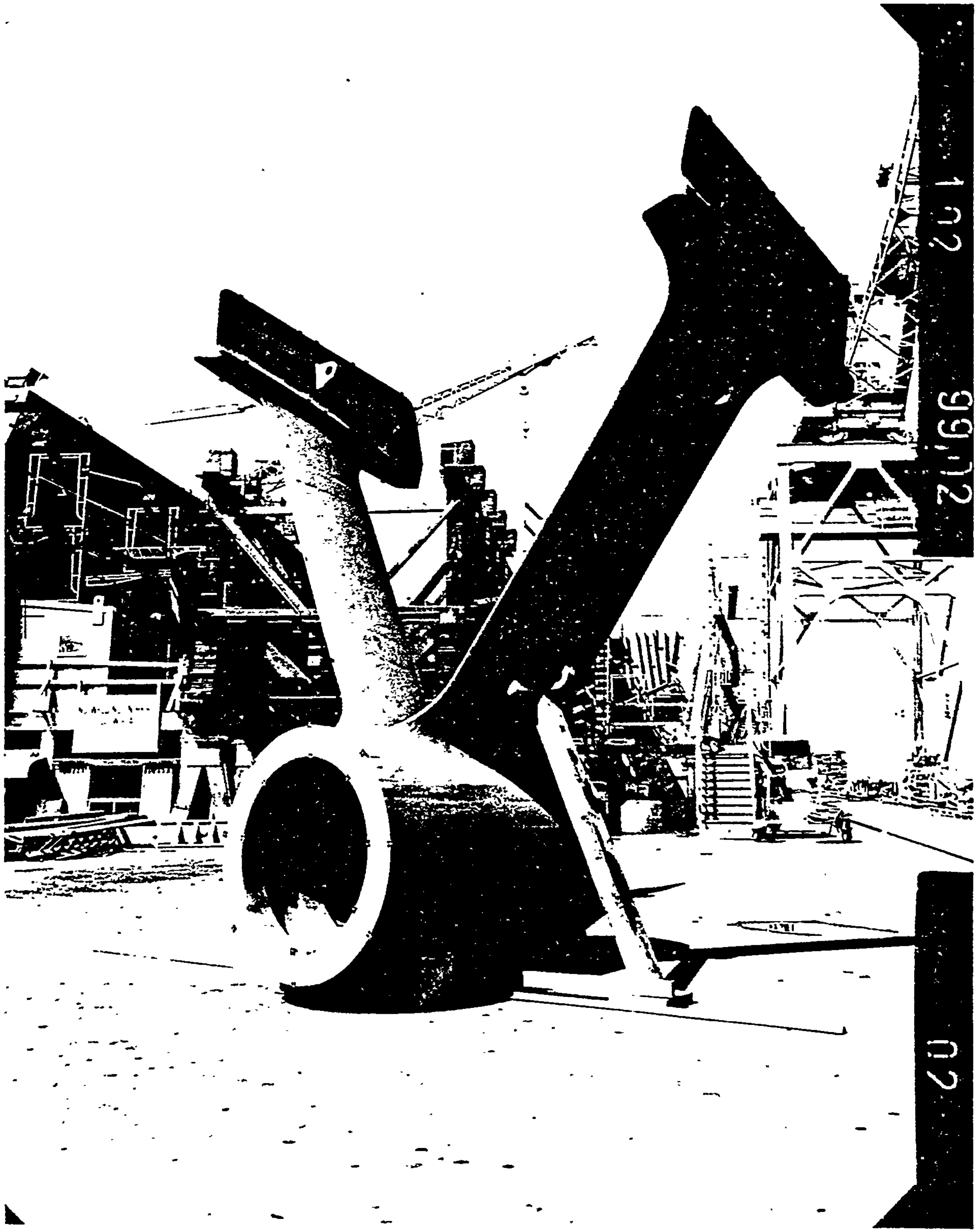

FIGURE 2-28: A Typical Photograph. From one of the original glass plate negatives exposed at a ground station.

TABLE 2-8

As-built Coordinates of Targetted Points. See paragraph 2.6.4 for description of the coordinate system and Figures 2-24 for locations of targets on the casting. All are in feet.

POINT	X	Y	Z	POINT	X	Y	Z
PORT OUTBD PALM				STBD OUTBD PALM			
1001	13.457	-7.498	8.533	4001	13.508	7.460	8.566
1002	13.705	-7.455	6.546	4002	13.747	7.449	6.573
1003	13.880	-7.430	5.167	4003	13.912	7.432	5.196
1004	13.955	-7.415	4.579	4004	13.986	7.427	4.588
1005	14.204	-7.378	2.590	4005	14.224	7.415	2.597
1006	10.984	-7.747	8.374	4006	11.028	7.686	8.342
1007	11.380	-7.789	6.401	4007	11.397	7.766	6.385
1008	11.645	-7.737	5.021	4008	11.647	7.736	4.998
1009	11.775	-7.670	4.423	4009	11.782	7.694	4.420
1010	12.203	-7.513	2.437	4010	12.200	7.544	2.435
1011	10.682	-7.753	8.314	4011	10.718	7.678	8.291
1012	11.075	-7.797	6.346	4012	11.092	7.743	6.327
1013	11.341	-7.733	4.968	4013	11.370	7.724	4.946
1014	11.472	-7.687	4.366	4014	11.482	7.684	4.355
1015	11.892	-7.527	2.409	4015	11.907	7.528	2.369
PORT INBD PALM				STBD INBD PALM			
2001	13.466	-7.324	8.533	3001	13.514	7.288	8.567
2002	13.713	-7.277	6.533	3002	13.750	7.274	6.578
2003	13.884	-7.256	5.166	3003	13.913	7.256	5.187
2004	13.964	-7.242	4.570	3004	13.988	7.250	4.594
2005	14.216	-7.201	2.587	3005	14.229	7.227	2.602
2006	10.969	-6.589	8.250	3006	10.941	6.497	8.234
2007	11.234	-6.425	6.267	3007	11.281	6.384	6.258
2008	11.503	-6.312	4.888	3008	11.536	6.288	4.900
2009	11.639	-6.279	4.278	3009	11.667	6.277	4.286
2010	12.059	-6.364	2.323	3010	12.076	6.389	2.335
PORT ARM LEADING EDGE				STBD ARM LEADING EDGE			
5004	8.636	-5.523	5.970	5001	8.624	5.457	6.002
5005	6.090	-3.952	5.661	5002	6.078	3.893	5.683
5006	3.522	-2.422	5.353	5003	3.532	2.400	5.370
PORT ARM TRAILING EDGE				STBD ARM TRAILING EDGE			
6004	9.188	-5.227	2.789	6001	9.181	5.195	2.810
6005	6.621	-3.686	2.476	6002	6.610	3.645	2.491
6006	4.070	-2.107	2.167	6003	4.080	2.088	2.175
FWD END BARREL				AFT END BARREL			
5007	2.244	-0.019	7.001	6007	2.428	-0.017	0.000
5008	1.645	-1.517	7.000	6008	1.731	-1.670	-0.000
5009	0.157	-2.224	7.000	6009	0.274	-2.398	-0.001
5010	-1.638	-1.538	7.000	6010	-1.538	-1.883	-0.001
5011	-2.235	-0.013	6.998	6011	-2.442	0.034	-0.003
5012	-1.503	1.655	7.001	6012	-1.375	2.010	-0.001
5013	0.144	2.233	7.001	6013	0.240	2.394	0.001
5014	1.615	1.510	7.003	6014	1.869	1.539	0.002
5015	1.811	-0.022	7.000	6015	1.813	0.068	0.000
5016	1.294	-1.267	7.001	6016	1.295	-1.273	0.001
5017	0.128	-1.808	7.000	6017	0.213	-1.803	0.000
5018	-1.252	-1.310	6.999	6018	-1.112	-1.434	-0.001
5019	-1.810	0.065	7.000	6019	-1.815	-0.053	-0.001
5020	-1.155	1.396	7.000	6020	-0.948	1.548	-0.000
5021	0.120	1.809	7.001	6021	0.220	1.802	-0.000
5022	1.317	1.243	7.001	6022	1.389	1.167	0.001
POINT	X	Y	Z	POINT	X	Y	Z

system at a scale of approximately 1:1 relative to the actual casting. Resultant coordinates for targets on the angle iron were then used to calculate the distances between the two target pairs. Each calculated distance was divided into the corresponding known value (as determined by measurement with the steel tape) to find its scale factor. The average of the two scale factors was then applied to all of the photogrammetrically derived target coordinates to bring them to an exact 1:1 scale relative to the casting.

The next step was to translate and rotate the arbitrary photogrammetric coordinate system into a coordinate system that best served the shipyard's QA inspector. This new coordinate system was defined as follows:

a. The origin was to lie at the center of the inside circumference at the after end of the barrel. Since a target could not be physically placed at this location there were no coordinates for it upon conclusion of the photogrammetric triangulation. It was necessary to "create" the point by calculating the center of the circle which best fit the eight targets on the inside circumference at the after end of the barrel.

b. The Z-axis of the coordinate system was the line defined by the calculated center of the inside circumference of the after end of the barrel and a point similarly obtained by calculating the center of the circle which best-fit the eight targets on the inside circumference at the forward end of the barrel[1].

c. Per an option elected by the shipyard's QA inspector the two targets[2] at the top inside faces of the palms and on the designer's transverse datum plane for the strut arms were to have equal but opposite offsets. These are reported as "Y" values. Thus, the values reported for "X" are elevations.

These transformed coordinates were computer-listed and provided to the shipyard in the form shown in Table 2-8. They could have been compared to the design by computer if corresponding design dimensions were in a single coordinate system.

2.6.5 Evaluation of Results

The X, Y and Z coordinates derived from the photogrammetric triangulation were accurate within an estimated tolerance of ±l/32 inch. Although this was much better than that required by the shipyard, it was a natural result of the multiplicity of rays intersecting each target. This high order of accuracy resulted from the need for eight camera stations to assure complete photograph coverage of the casting's complicated shape.

[1] The best-fit circle computations also provided a check on the rough bore's circularity. As requested by the construction superintendent, *targets* were also placed to define the outside circumferences of the barrel. They facilitated verification of the concentricity of the bore relative to the barrel and the perpendicularity of the machining allowances on both barrel ends.

[2] Targets numbered 2003 and 3003 in Figure 2-24a.

TABLE 2-9: Time and Cost Analysis; circa July 1978

PHOTOGRAMMETRIST'S LABOR

	Man-Hours	Burdened Rate[1]	Cost
a. Project planning and coordination (1 man)	26	$22.25	$578
b. Prepare equipment[2] and round trip travel (1 man)	25	22.25	556
c. Setup, photography, processing and packing (1 man)	13	22.25	289
d. Prepare diagrams and plates for measuring (1 man)	9	22.25	200
e. Measure plates (subcontracted)	—	—	202
f. Data preparation and processing (1 man)	29	22.25	645
g. Reporting (1 man)	12	22.25	267
h. Miscellaneous (1 man)	5	22.25	111

Total Labor $2,848

PHOTOGRAMETRIST'S EXPENSES

a. Targets	$25
b. Transportation and per diem[2]	694
c. Photographic materials	205
d. Computer	312
e. Miscellaneous	185

Total Expenses $1,421

$4,269

Profit @ 20% 854

TOTAL $5,123

SHIPBUILDER'S LABOR

	Estimated Man-Hours
a. Model builder	16
b. Carpenters	3
c. Riggers	4
d. Crane operator	2
e. Forklift operator	5
f. QA man (layout reference lines and targetting)	4

TOTAL . . . . 34 man-hours

SHIPBUILDER'S EXPENSES

	Cost
a. Model materials	$5
b. Timber	20

TOTAL $25

1Rates vary among firms.

2For a Florida-based photogrammetric firm working in Seattle, Washington.

2.6.6 Time and Cost Analysis

Table 2-9 itemizes the photogrammetrist's efforts as if a shipyard were to contract for a complete service. The shipyard's labor and material expenditures are nominal and are also given therein.

2.6.7 Suggestions Relative to Implementation

Because increasingly fewer foundries are fabricating large castings, shipbuilders are oftentimes considerably removed from the manufacturing facility. In fact, it is not uncommon for large castings to be fabricated in a foreign country. In such instances it may be practical for suitable photographs of a casting to be taken at the foundry and forwarded to the shipyard or its photogrammetric consultant for evaluation[1].

From descriptions given in paragraphs 2.6.1 and 2.6.2 it is seen that the field work for taking photographs of a casting is not complicated. With specific instructions and a special camera it is feasible for a non-photogrammetrist to secure the required photographs. Once they are photogrammetrically processed the shipyard's QA inspector would have an irrefutable[2] report of the dimensions achieved by the foundry. Also, if only a few large complex castings are required the foundry may also benefit because photogrammetric measurement can eliminate the need for constructing an elaborate measuring jig.

Another shipbuilding consideration derives from the inherent accuracy of photogrammetry and the relatively large tolerances necessarily allowed for large castings. Photogrammetrically obtained offsets, such as from the 93 ton, 24-foot high sternframe in a Polar class icebreaker, could be substituted for the molded design. This would permit the adjoining heavy shell plating[3] to be developed, cut and shaped to better fit a particular casting.

Although not a photogrammetric consideration, note was made during the demonstration described herein that the design featured a series of interdependent references from which measurements were expressed in fractions, decimals and degrees. Thus, the pattern maker, the QA inspectors in the foundry and shipyard, and the production people who installed the strut, all had to calculate additional dimensions between points on the strut surfaces in order to fulfill individual needs. If designers, having the best opportunity, identify certain points on the surface[4] of a casting[5] in accordance with a single coordinate system oriented to the casting itself, it would enhance productivity of the overall process from design through installation.

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[1] At least two U.S. shipbuilders and two airplane manufacturers, aS of January 1979, are considering "in-house" photogrammetric capabilities.

[2] The process is analytical. If another photogrammetrist applied the same methods to the same photographs, the same dimensions and tolerances would be achieved.

[3] Modified ASTM 537 steel plate l-3/4" thick.

[4] For example points such as those in Figure 2-24a designated by targets 1001,1006, 1011, 2001 and 2006. They define the projection of a frame station. If represented on the pattern they could have appeared on the casting to facilitate both inspection and installation.

[5] Any casting, e.g. sternframe, hawsepipe, etc.